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TNO report

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**Loss of military performance due to individual
NBC protection in a tropic environment**

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Belasting en prestatieverlies door individuele NBC-bescherming in de tropen

Het werken in NBC-beschermende kleding en uitrusting is zeer belastend en kan leiden tot prestatieverlies tijdens de uitvoer van militaire taken. Met een aantal korte onderzoeken met militairen die in een tropisch klimaat taken hebben uitgevoerd met NBC-bescherming hebben we meer inzicht gekregen in de effecten van het dragen van NBC-bescherming op de militair.



Probleemstelling

Binnen het programma V013 'Passieve bescherming tegen NBC wapens' is behoefte aan kennis over belasting en het prestatieverlies door het dragen van NBC-beschermende kleding en uitrusting. Hiervoor hebben we veelal laboratorium-experimenten uitgevoerd. Om meer inzicht te krijgen in het werken onder NBC-omstandigheden in de praktijk was tevens behoefte aan veldexperimenten in een tropisch klimaat.

Beschrijving van de werkzaamheden

Voor dit onderzoek hebben we ons aangesloten bij veldmetingen van het project 'Protectiefactor te Velde' uitgevoerd in het kader van de Anglo Netherlands Norwegian cooperation on chemical protection (ANNCP). Deze metingen vonden plaats op het eiland Curaçao in de Nederlandse Antillen. Tijdens het onderzoek hebben we metingen verricht aan Nederlandse Mariniers die werkzaamheden verrichtten in NBC-beschermende kleding.

Resultaten en conclusies

Werken in NBC-beschermende kleding en uitrusting in een warm klimaat is zeer belastend voor militairen. Dit uit zich in een meetbare afname van de militaire prestatie in het veld. Het dragen van een gasmasker tijdens een speed-mars draagt bij aan een stijging van de kerntemperatuur en een afname van de marssnelheid. Het dragen van NBC-handschoenen en een gasmasker zorgden voor een verslechtering van de handvaardigheid en de vingervaarigheid.

Toepasbaarheid

De resultaten uit dit onderzoek geven een eerste indicatie over het te verwachten prestatieverlies in het veld ten gevolge van het dragen van (delen) van de huidige Nederlandse NBC-beschermende kleding en uitrusting. Tevens maken de resultaten uit dit onderzoek het mogelijk om meer onderscheidende laboratorium- en veldtesten op te zetten om het militaire prestatieverlies door NBC-beschermende kleding en uitrusting te kwantificeren.

Belasting en prestatieverlies door individuele NBC-bescherming in de tropen

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Frequentie van overleg Met de programma/projectbege- leider werd tijdens de uitvoer van het project gemiddeld iedere maand gesproken over de invulling en de voortgang van het onderzoek.	Projectteam drs. P.A. Reffeltrath, ing. T.K. Tan

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Samenvatting

Inleiding

In het kader van het programma V013 is onder meer onderzoek verricht naar de belasting en het prestatie verlies door het dragen van NBC-beschermende kleding en uitrusting. Hiervoor wordt veelal gebruik gemaakt van laboratorium experimenten. Ten einde meer inzicht te krijgen in het werken onder NBC-omstandigheden in de praktijk is een veldexperiment uitgevoerd in een tropisch klimaat.

Methode

Dit onderzoek is uitgevoerd tijdens veldmetingen van het project 'Protectiefactor te Velde' in het kader van de Anglo Netherlands Norwegian Cooperation on Chemical Protection (ANNCP). De metingen vonden plaats op het eiland Curaçao in de Nederlandse Antillen. Tijdens het onderzoek zijn metingen verricht aan de fysiologie en de prestatie van Nederlandse Mariniers die werkzaamheden verrichtten in NBC-beschermende kleding. De moeilijk te controleren variabelen tijdens een veldtest en het geringe aantal proefpersonen maken statistisch toetsen niet zinvol, daarom is descriptief onderzoek uitgevoerd.

Resultaten

Het dragen van een gasmasker tijdens een speedmars uit zich in een verhoging van de hartslag en een grotere stijging in de kerntemperatuur dan zonder gasmasker. Tevens was de snelheid van de speedmars lager wanneer er een gasmasker werd gedragen dan zonder gasmasker. Het dragen van een volledige NBC-uitrusting leidde tot een afname in prestatie op handvaardigheidtaken van meer dan 30%. Er is geen relatie gevonden tussen de omgevingstemperatuur en het ervaren comfort, thermisch comfort en uitputting met volledige NBC-uitrusting. Ook leidde het dragen van deze uitrusting niet tot veranderingen in de stemming van de militairen.

Conclusies

Werken in NBC-beschermende kleding en uitrusting in een warm klimaat is zeer belastend voor militairen. Dit uit zich in een meetbare afname van de militaire prestatie in het veld. De effecten op de ervaren belasting en de stemming van de militairen zijn minder duidelijk.

Summary

Introduction

As part of the program 'Passive protection against NBC weapons' research was performed into the effects of NBC protection on military performance. This was mostly done using laboratory experiments. To obtain more knowledge about working in the field under NBC protection a field experiment was performed in a tropical climate.

Methods

This study was performed during field trials of the project 'protection factor in the field', which was performed within the framework of the Anglo Netherlands Norwegian Cooperation on Chemical Protection (ANNCP). These trials were conducted in Curaçao on the Netherlands Antilles. In the course of the study measurements were performed on the physiology and performance of Dutch Marines working in NBC protective clothing. Due to the nature of the trials it was not always possible to perform the tests with an adequate number of subjects. Only descriptive research was therefore performed.

Results

Wearing a respirator during a speed-march results in an increased heart rate, a rise in core temperature and a reduction in speed. Wearing full NBC protection can result in a reduction of more than 30% in manual dexterity tasks. No relation was observed between the environmental temperature and the perceived comfort, thermal comfort or exertion when wearing full NBC protection. Wearing this equipment did not result in changes in the mood of the soldiers.

Conclusion

Using NBC protective clothing in a tropic environment is a heavy physiologic burden for soldiers. This can lead to measurable loss of military performance in the field. The effects on perceived strain and mood of the soldiers are less clear.

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1 Introduction

Recently, an inventory of the effects of NBC protection on military performance was made (Reffelltrath and Van Es, 2004). Although several effects of NBC protection on performance can be found in a laboratory setting (Daanen and Koerhuis, 2003) it was unclear if these effects could also be measured in the field. In this study we made a first attempt to measure the performance, and some factors known to affect performance of Dutch Marines in a tropical environment. A secondary goal was to test the usability of a data acquisition and monitoring system for heart rate and core temperature.

In November 2004 experiments were performed with Dutch marines based on the island Curaçao in the Caribbean (Figure 1). For this we joined a study of respirator protection factors in the field. The trials were conducted in Curaçao on the Netherlands Antilles under the flag of the Anglo Netherlands Norwegian Co-operation on Chemical Protection (ANNCP).



Figure 1 The island Curaçao in the Dutch Antilles.

During the two weeks of experiments a total of 10 Marines in changing groups of four participated in this study. All measurements with NBC equipment were performed on soldiers wearing the FM-12 respirator combined with combat trousers, a T-shirt and (on all occasions except for the speed-march) the M2000 NBC suit.

The marines who participated in the study were asked to perform several military tasks (shooting, speed-marching, obstacle course etc.) while wearing NBC protective clothing. To monitor the heart rate and core temperature of the marines during the trails a Coretemp unit (HTI CORETEMP 2000) with radio frequency transducer (RF module) was used. This system is able to record the core temperature through an ingested pill and the heart rate through a polar belt, transmitting this data to a receiver that is

connected to a computer. The Coretemp software allows the core temperature and heart rate of several subjects to be displayed real-time on the screen and to be stored on the computer. To assess the military performance of the Marines four tests were used: a speed-march, a manual dexterity test, subjective scales during a Standard Military Procedure (SMP) and the Profile Of Mood Scale (POMS) (Wald and Mellenbergh, 1990). A speed-march is a form of movement for quick withdraws from a dangerous area. A speed-march consists of alternating periods of running and walking. Typically, soldiers will use 2-minute periods for running and 1-minute periods for walking. Speed-marching might be the option a unit chooses to get out of an area that is under (chemical) attack. However, it is unclear if wearing NBC protection will result in a substantial loss of speed. Earlier research showed that speed-marching on the Island of Curaçao is a very heavy task due to the extremely high metabolic rate that results in high levels of heat stress (Havenith and Vrijkotte, 1993). During the trials described in this report the effects of wearing a respirator on the soldiers' physiology and performance during a speed-march were studied.

The ability to manipulate small objects is very important for soldiers. Not only to handle weapons but more and more electronics are emerging on the battlefield that require manual dexterity. Johnson and Sleeper (1986) reported that fine motor skills decrease with 40% due to wearing NBC gloves. In this experiment the dexterity is not only influenced by the thick rubber gloves, but also by the reduced view due to wearing a respirator.

A Standard Military Procedure (SMP) was designed to study the influence of movements and actions that are common for soldiers on the respirator protection factor. During the trial in Curaçao this SMP was also used to study the effect of working in full NBC protective equipment in tropical environments on comfort, thermal comfort, moisture perception and perceived exertion.

Respirators can impose a feeling of isolation from the surrounding world, which causes an increase in stress and therefore a decrease in performance and effective task completion. To investigate the psychological effects of personal NBC protection all subjects were asked to fill in a questionnaire containing questions about their mood state on multiple occasions during the trials.

The following program was performed during the 2-week trial.

DTG (b)	(c)	EVENT (d)	LOCATION (e)
15 nov	0800-1100	Office Call Base Commander, Med Facility Soldiers Induction Briefings	NL Mil Base
	1100-1200	Standard Military Procedure (SMP) 1	Trg Area
	1330-1430	SMP 2	Trg Area
16 nov	0800-0900	SMP 3	Trg Area
	0930-1200	Offensive Fire – LIVE FIRE Range 1	Range Complex
	1300-1530	Command & Control Evaluation (C2) 1	Range Complex
	1600-1700	SMP 4	Trg Area
17 nov	0930-1200	Defensive Fire – LIVE FIRE Range 2	Range Complex
	1300-1530	Command & Control Evaluation (C2) 2	Range Complex
18 nov	0800-0900	SMP 5	Trg Area
	0930-1200	Offensive Fire – LIVE FIRE Range 2	Range Complex
	1300-1530	Command & Control Evaluation (C2) 3	Range Complex
	1600-1700	SMP 6	Trg Area
19 nov	0900-1400	Combat Speed-march – 12 km No NBC kit	Trg Area
22 nov	0930-1030	Human Factors Integration – Vehicle Trial	Trg Area
	1100-1200	Individual Manoeuvrability Trials	Assault Course
	1400-1700	Counter Mine – Tactical Clearance 1	Range Complex
23 nov	0800-0900	SMP 7	Trg Area
	0930-1030	Human Factors Integration – Vehicle Trial	Range Complex
	1100-1200	Individual Manoeuvrability Trials	Assault Course
	1300-1530	Long Range Chem Recce Patrol	Trg Area
	1600-1700	SMP 8	Trg Area
24 nov	0800-0900	SMP 9	Trg Area
	0930-1200	Combat Speed-march – 12 km	Trg Area
	1400-1700	Counter Mine – Tactical Clearance 2	Trg Area
25 nov	0900-1700	Spare Trials Day – Poss Helicopter	

2 Experiences with the Coretemp + Rf module

The Coretemp unit (HTI CORETEMP 2000) with radio frequency transducer (RF module) is able to record the core temperature through an ingested pill and the heart rate through a polar belt, transmitting this data to a receiver that is connected to a computer (Figure 2). The Coretemp software allows the core temperature and heart rate of several subjects to be displayed real-time on the screen and to be stored on the computer.



Figure 2 The set-up at the shooting range.

The RF unit performed well during the tests. Although the transmitter covers a limited distance the signal was received rather well; even if the transmitter (including the antenna) was worn under the NBC suit, with much electrical equipment attached to the soldiers. The software is easy to use and enabled us to monitor the core temperature and heart rate of the soldiers. Since the transmitter has a limited reach we used the system mobile as well (Figure 3). It would be beneficial if the system itself was more prepared for mobile use.



Figure 3 Mobile monitoring during the obstacle course.

The Coretemp unit itself performed less satisfactory. A lot of incorrect values appeared in the data and sometimes the connection with the pill was temporary lost without a clear cause. After filtering the data, the data could still be used, but valuable data points were lost. Overall, it was a good opportunity to become acquainted with the system. In summary, the RF unit performed well, but the temperature measurements were not fully reliable.

3 Speed-march

Four male Marines were measured during a routine speed-march on a hardtop road with and without NBC protection. The Wet Bulb Globe Temperature (WBGT) varied between 28.5 °C and 29.5 °C during both speed-marches. During the speed-march tests the following measurements were performed.

- Core temperature by a pill (HTI CORETEMP 2000) that was ingested by the subjects 4 hours prior to the measurements. Core temperatures were sent by radio to a transmitter, which was connected to a laptop. This allowed online monitoring of the subjects core temperatures.
- Heart rate (Polar Sporttester, Polar Electro, Finland).
- Lap time measured with a stopwatch.

For safety reasons subjects reaching a core temperature above 39 °C were asked to stop walking and all subjects were instructed to stop if they felt unfit to continue. During the speed-march without NBC protection all four subjects were able to complete the 4.4 Km march. While wearing a respirator (but no NBC clothing) only one subject could complete the march. One subject was pulled out of the march after 21 minutes because core temperature exceeded 39 °C. Two other subjects stopped after 28 minutes on their own initiative. The average speed during the baseline speed-march was 8.1 Km/hour while the average speed while wearing a respirator was 7.5 Km/hour (Table 1). In round 1 wearing a respirator resulted in an increased speed. This was later compensated by underperformance.

Table 1 Speed-march performance with and without a respirator.

Round	Respirator		No respirator	
	Speed	Drop-outs	Speed	Drop-outs
1	9.4 Km/h	0	8.2 Km/h	0
2	7.3 Km/h	0	8.1 Km/h	0
3	6.6 Km/h	1	8.2 Km/h	0
4	7.3 Km/h	3	8.1 Km/h	0
Average	7.5 Km/h		8.1 Km/h	

During the speed-march with and without wearing a respirator the core temperature of the subjects showed a steep increase (Figure 4). Although the respirator only covers a small part of the body and the weight carried by the subjects was standardised for both conditions, the increase in core temperature with a respirator was higher than without.

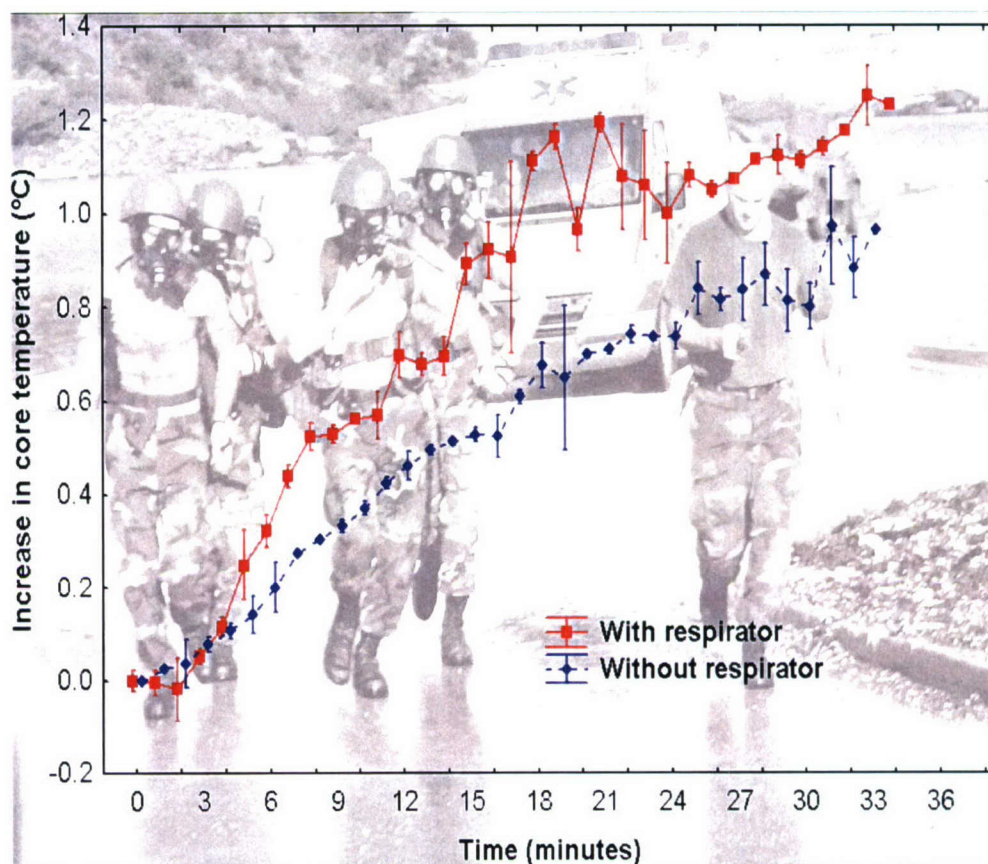


Figure 4 Mean (sd) increase in core temperature during the speed-march with and without a respirator.

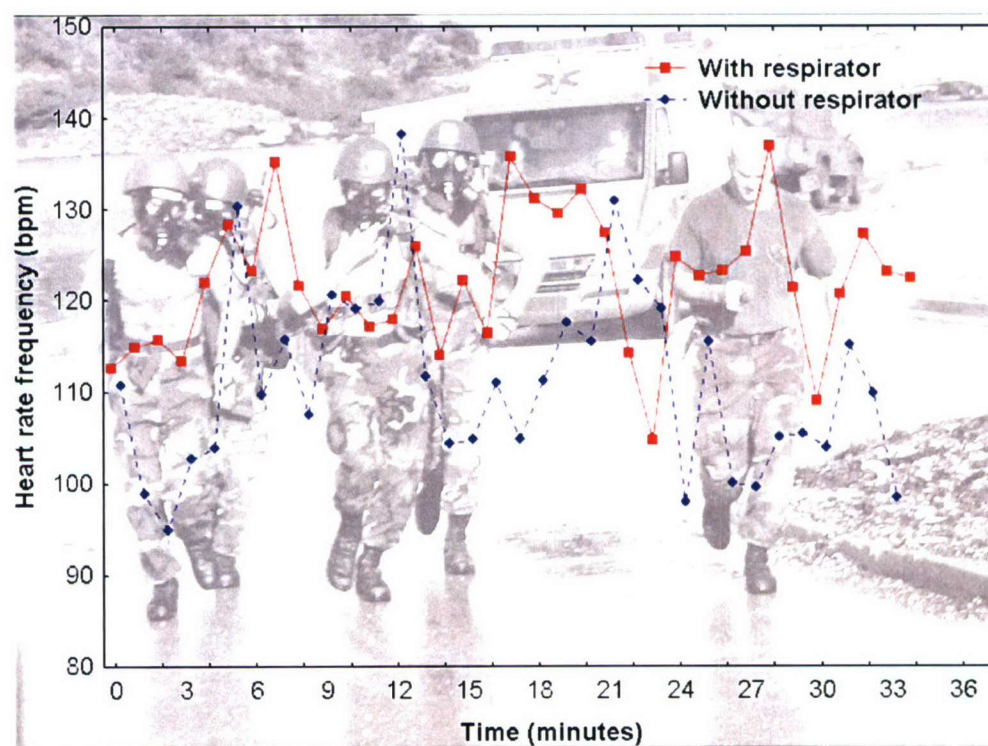


Figure 5 Mean heart rate during the speed-march with and without a respirator.

Although the heart rate measurement results are rather difficult to analyse due to the alternate walking and running during a speed-march (Figure 5), differences were observed in the overall mean, minimum and maximum heart rate between the conditions. Note that towards the end of the speed-march with respirator the number of subjects drops. Table 2 shows that the average as well as the minimum and maximum heart rate was higher while wearing a respirator than without.

Table 2 Results of the heart rate measurements during the speed-march.

	NBC	No NBC
Min	46	31
Mean	121	108
Max	252	219
Sd	23	24

4 Dexterity

Eight male Marines participated in the dexterity tests. Manual dexterity was assessed on 6 occasions during the two-week period of the trial. The Minnesota Manual Dexterity Test (designed to assess unilateral and bilateral manual dexterity along with eye-hand coordination) and the Purdue Pegboard Test (designed to assess fine and fingertip dexterity along with eye-hand coordination) were used to measure manual dexterity with and without NBC equipment (respirator, gloves and suit). On each occasion the subjects performed 3 repeated Minnesota tests and 3 repeated Purdue tests. Both tests were performed using two hands.

While wearing NBC protection the subject needed more time to complete the dexterity tests (Figure 6). With NBC protection the average completion time for the Minnesota test increased with 39% while the average completion time for the Purdue test increase with 32%.

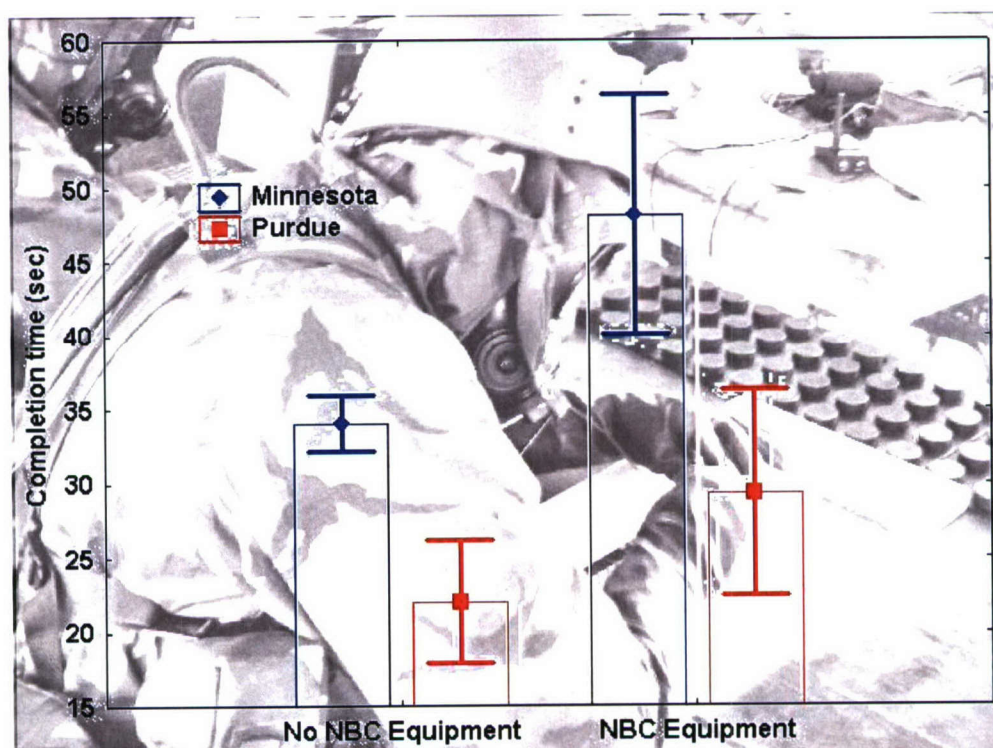


Figure 6 Mean (sd) completion time of the dexterity test with and without NBC equipment.

5 Standard Military Procedure (SMP)

The SMP consists of a series of movements and tasks with relevance to military operations and that are likely to have an impact on the protective performance of the respirator. The course of action during the SMP is listed in Table 3. The schedule of the SMP's is listed in Table 4.

Table 3 Course of action during the Standard Military Procedure (SMP).

Action	Time, distance or number
rest	2 min
Nodding Yes	1 min
Rest	1 min
Shaking No	1 min
rest	1 min
Walking (3.5 km/h)	2 min
rest	1 min
Digging sand	2 min
rest	1 min
Crawling on hands and knees	18 metres
rest	1 min
Running (12 km/h)	2 min
rest	2 min
Taking cover	3 times in 1 minute
Rest	1 min
Crawling on knees and elbows	18 metres
Rest	1 min
jumping	3 times in 1 minute
rest	1 min
Climbing (not done in Curaçao)	3 times in 1 minute
Rest	1 min
Throwing grenade	3 times in 1 minute
Rest	1 min
lifting	3 times in 1 minute
Total	30 minutes

Table 4 SMP schedule.

Date	Time	SMP
15 nov	Morning	SMP 1
	Afternoon	SMP 2
16 nov	Morning	SMP 3
	Afternoon	SMP 4
18 nov	Morning	SMP 5
	Afternoon	SMP 6
23 nov	Morning	SMP 7
	Afternoon	SMP 8
24 nov	Morning	SMP 9

To obtain subjective information concerning the subjects’ comfort and exertion during the successive SMP tests the following subjective scales were used:

- Comfort (ISO 10551, 1995);
- Thermal comfort (ISO 10551, 1995);
- Moisture perception;
- Rate of Perceived Exertion (Borg, 1982).

During the SMP tests the WBGT was monitored with a WBGT thermometer. No relation between the WBGT and subjective scales was found. Even no relation between the WBGT and the perceived temperature could be observed. A trend was observed that the more often the Marines performed the SMP protocol, the less discomfort and exertion they experienced (Figures 7, 8 and 10). Only the moist perception of their underwear showed a relation with the WBGT (Figure 9).

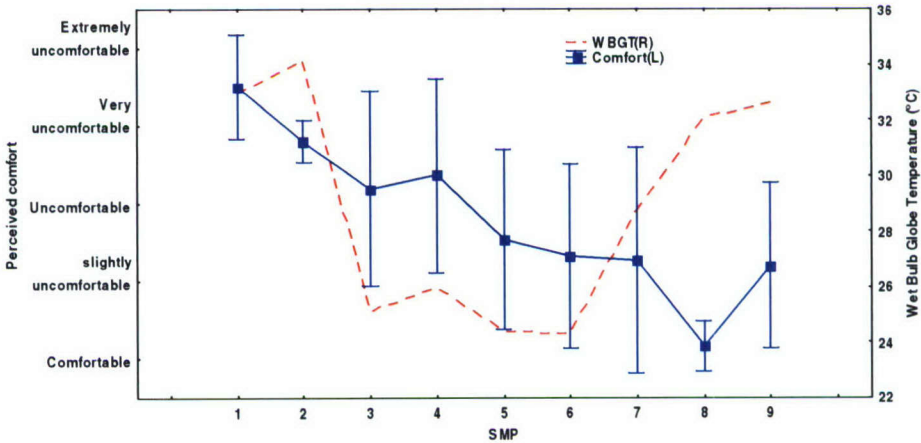


Figure 7 Median and 95% confidence interval of the comfort (left) and measured WBGT (right) during the nine SMP sessions.

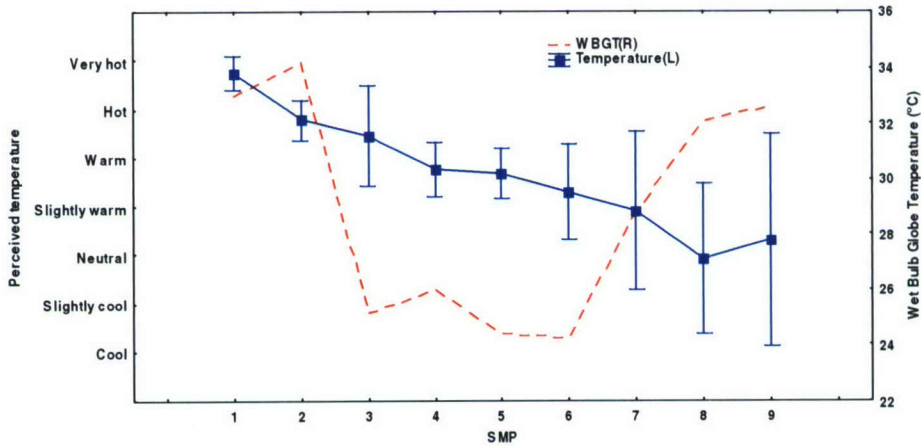


Figure 8 Median and 95% confidence interval of the perceived temperature (left) and measured WBGT (right) during the nine SMP sessions.

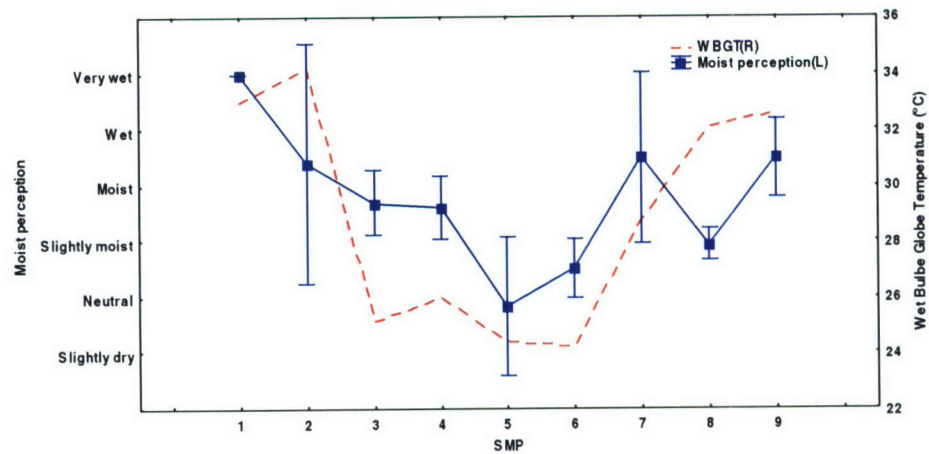


Figure 9 Median and 95% confidence interval of the moisture perception (left) and measured WBGT (right) during the nine SMP sessions.

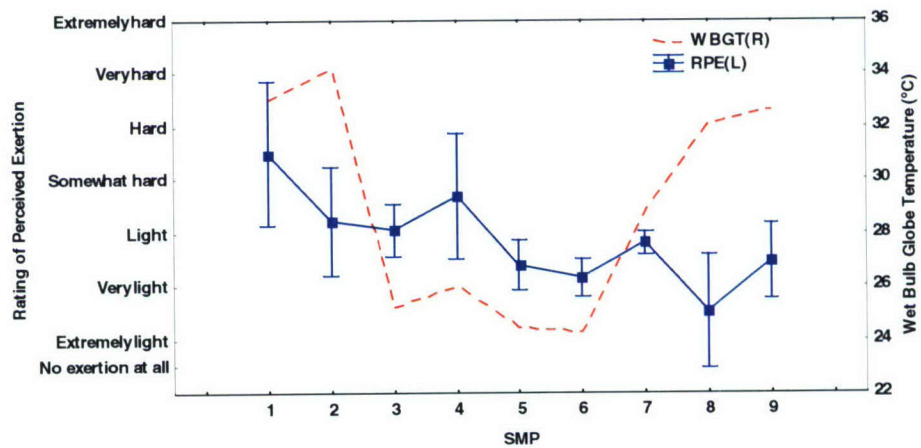


Figure 10 Median and 95% confidence interval of the rating of perceived exertion (left) and measured WBGT (right) during the nine SMP sessions.

6 Mood

On four separate occasions eight male Marines answered questions about their mood state while wearing NBC protection. The psychological effects of NBC protection were analysed with the use of POMS (Profile Of Mood Scale) (Wald and Mellenbergh, 1990).

Wearing NBC protection did not seem to result in feelings of depression, anger, fatigue or tension in these Marines.

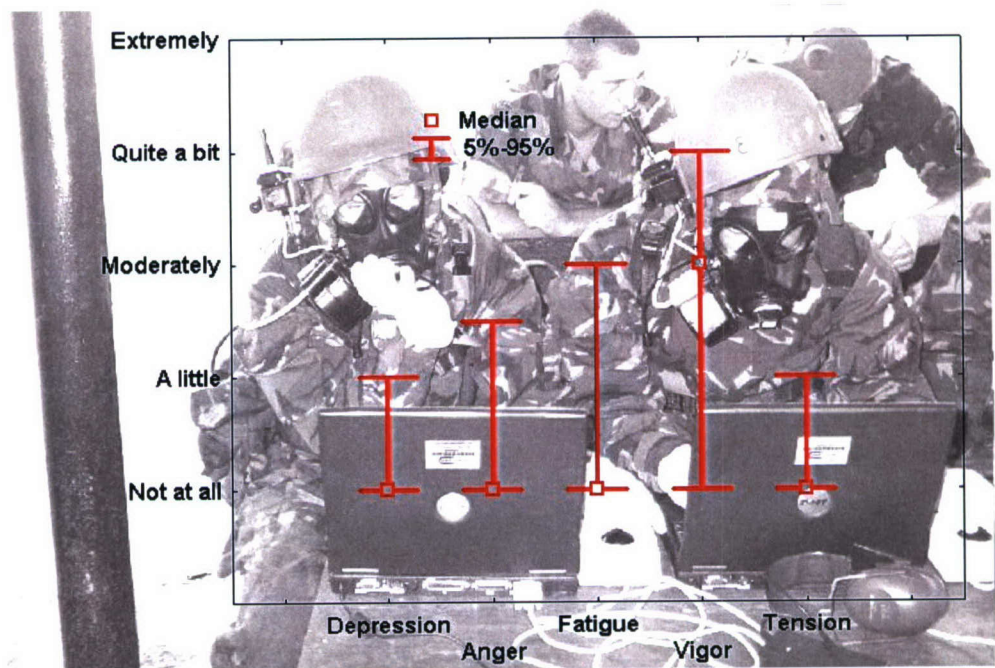


Figure 11 Median and 95% confidence interval of the mood states of the marines wearing full NBC equipment.

7 Discussion

To obtain more knowledge about working in the field under NBC protection and how to measure performance loss under these conditions, a field experiment was performed in a tropical climate. The trials described in this report provided us with insight in the effects of NBC protective equipment on soldier performance in the field. Due to the nature of the trials it was not possible to acquire statistically sound scientific data.

Speed-march

Although the number of subjects was too small to generate reliable results the data suggest that wearing a respirator during a speed-march results in an increased heart rate, a rise in core temperature and a reduction in speed. This might have serious consequences for soldiers who are trying to escape from a contaminated area. An increase in body temperature and heart rate can make the human body more vulnerable for NBC-agents while a reduction in mobility might increase the time the soldier is exposed to NBC-agents.

The speed results are somewhat polluted by the fact that the subjects who suffered from mild hyperthermia or became exhausted, had to stop running. During an actual mission these subjects would have slowed down the speed-march even more.

Since the respirator only covers a small part of the body and the weather conditions of the march with and without respirator were comparable the increase in core temperature cannot be explained by a reduced heat loss. If so, the heat production during the march with respirator should have increased. Because the weight of the equipment with and without respirator was standardised, the increased heat production might be caused by the respiratory resistance of the respirator.

Dexterity

Loss of dexterity due to wearing NBC protective clothing was shown by using the Minnesota Manual Dexterity Test and the Purdue Pegboard Test. It is unclear why the loss of performance is bigger for gross manual dexterity than for fine manual dexterity. Due to the set-up of the test (with or without the complete NBC protective equipment), it is also not clear which factor (gloves, respirator or clothing) is responsible for which fraction of the performance decrement.

SMP

No relation between WBGT and subjective scales was found. A trend was observed that the more often the Marines performed the SMP protocol the less discomfort and exertion they experienced. This could be due to a large training effect by which the soldiers become accustomed to working in NBC clothing and were acclimatising to the hot microclimate inside the NBC suit. These effects could be masking the effect of the ambient temperature.

Mood

The findings in this study support earlier (unpublished) observations in the laboratory that the POMS is not a suitable method to obtain information about mood states of soldiers. Soldiers are not accustomed to report their mood state. Therefore, we think that the POMS is not sensitive for this population.

8 Conclusion

Using NBC protective clothing in a tropic environment can lead to measurable loss of military performance in the field. Although the number of subjects was too small to generate reliable results, the data suggest that wearing a respirator during a speed-march in a tropical environment results in an increased heart rate, a rise in core temperature and a reduction in speed. Wearing NBC protective clothing can result in a reduction of manual dexterity. No relation between WBGT and subjective scales was found. A trend was observed that the more often the Marines performed the SMP protocol the less discomfort and exertion they experienced. Wearing full NBC protection did not lead to measurable effects on the mood of the Marines.

In future field trials a more reliable system to measure core temperatures should be used that is also more qualified for mobile use. If possible, metabolic rate measurements of the soldiers in the field should be included in the trials. Also, the performance of more operational tasks (shooting, sprinting) should be included.

If future trials are used to gather reliable data concerning soldier strain and performance, a balanced design consisting of conditions with and without protection should be used.

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10 Signature

Soesterberg, August 2006

TNO Defence, Security and Safety

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P.A. Reffeltrath, MSc
Project leader/First author

ONGERUBRICEERD
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14. SUPPLEMENTARY NOTES The classification designation Ongerubriceerd is equivalent to Unclassified, Stg. Confidentieel is equivalent to Confidential and Stg. Geheim is equivalent to Secret.		
15. ABSTRACT (MAXIMUM 200 WORDS (1044 BYTE)) To obtain more knowledge about working in the field under NBC protection a field experiment was performed in a tropical climate. This was performed during field trials of the project 'protection factor in the field', which was performed within the framework of the Anglo Netherlands Norwegian Cooperation on Chemical Protection (ANNCP). These trials were conducted in Curaçao on the Netherlands Antilles. In the course of the study measurements were performed on the physiology and performance of Dutch Marines in NBC protective clothing. Wearing a respirator during a speed-march result in an increased heart rate, a rise in core temperature and a reduction in speed. Wearing full NBC protection can result in a reduction of more than 30% in manual dexterity tasks. No relation was observed between the environmental temperature and the perceived comfort, thermal comfort or exertion when wearing full NBC protection. Wearing this equipment did not result in changes in the mood of the soldiers. It was concluded that using NBC protective clothing in a tropic environment is a heavy physiologic burden for soldiers. This can lead to measurable loss of military performance in the field. The effects on perceived strain and mood of the soldiers are less clear.		
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